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Arizona/Fire Based Restoration of Biodiversity in
Ecosystem Dominated by Nonnative Grasses

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The introduction of nonnative species in the United States has resulted in significant environmental damage and economic losses exceeding \$1 billion per year. We assessed the influence of nonnative species on biological diversity in the southwestern United States in systems prone to fire using a rigorous experimental framework. Our specific objectives were to (1) determine effects of fire season on responses of biotic communities, and (2) quantify relationships between biological guilds before and after burning and through post-fire recovery. This experiment is taking place within grasslands and *Prosopis* savannas at the Fort Huachuca Military Reservation. The experiment evaluates the main and interactive effects of dominance by nonnative plants and fire season with three replicates in each of two years. Biomass of *Eragrostis lehmanniana* declined and persisted following burns for more than 2 years. The degree of the response was dependent on annual precipitation and fire season. Plant species richness did not change with fire treatments but remained lower on plots dominated by *E. lehmanniana* and higher on native-dominated plots. In general, species richness and relative abundance of small mammals decreased in the first year following fire. However, 2 years after fire, values approached that observed in unburned areas.

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Fire-based restoration of biodiversity in ecosystems dominated by nonnative grasses

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Introduction

As nonnative species continue to increase in distribution and abundance, so do their effects on native species. Nonnative species have tremendous environmental and economic costs and will continue to be a major problem in the future (Pimentel et al. 2000). For example, more than 50,000 nonnative species have established in the United States, at an annual cost of \$137 billion (Pimentel et al. 2000). Increases in some nonnative species have reduced or eliminated indigenous plants and animals, and thereby contributed to changes in species diversity and community composition (e.g., Bock et al. 1986, OTA 1993). These types of changes have consequential implications for ecosystem function (Naeem et al. 1996).

In the southwestern United States, establishment and spread of nonnative Lehmann lovegrass (*Eragrostis lehmanniana* Nees) and Boer lovegrass (*Eragrostis chloromelas* Steud.) may be disrupting native ecosystem processes at multiple spatial and temporal scales. Prescribed fire has been proposed as a restoration tool in these semi-arid systems, even though considerable evidence suggests that fires enhance establishment of these nonnative lovegrasses (e.g., Cable 1965, 1971, Ruyle et al. 1988, Sumrall et al. 1991, Robinett 1992, Biedenbender and Roundy 1996).

Because increased abundance of nonnative lovegrasses likely is detrimental to some native species and to overall biological diversity, we initiated an experimental assessment of the influence of fire regime on abundance of nonnative lovegrasses and biological diversity. Our specific objectives are to (1) determine effects of fire season on responses of biotic communities, and (2) quantify relationships between biological guilds before and after burning and for several years post-fire.

Body

Study sites

Our experiment was established in grasslands and *Prosopis* savannas at the base of the Huachuca Mountains (31° 34' N, 110° 26' W) of southern Arizona. Elevations range from 1420 to 1645 m. About 66% of average annual precipitation of 440 mm falls between July-October and 20% falls between December-March. A hot, dry period between late March and early July prior to the onset of monsoons is also characteristic.

Experimental Design

We have developed and implemented a split-plot experimental design with full-factorial treatment structure. Extant plant community is the whole-plot factor (levels: native grass dominated, nonnative lovegrass dominated, and mixed native and lovegrass, described below) and burn season is the treatment (spring fire, summer fire, no fire). Plots are 1 ha, which is large enough to minimize edge effects and to allow adequate sampling of the plant, invertebrate, and small mammal communities.

Plot Selection and Allocation

We identified 3 types of grasslands, representing a continuum of invasion by nonnative species:

- 1) Grasslands dominated by the nonnative grass *Eragrostis lehmanniana*
- 2) Native-dominated grasslands with *Aristida* spp., *Bothriochloa barbinodis*, *Bouteloua* spp., *Digitaria californica*, *Eragrostis intermedia*, and *Panicum* spp.
- 3) Grasslands composed of a mix of nonnative and native species.

In summer 1999, we chose 18 sets of sites at FHMR, 6 within each of these 3 types of grassland community. Within each site, we established 3, 1-ha plots. Each of the 3 plots within a site received 1 of 3 fire treatments, and we treated plots in 9 of 18 sites in both 2001 and 2002. We used 3 replicates per grassland community type ($n = 3$) per treatment ($n = 3$) in a given year ($n = 2$). We marked the corners of all plots with metal fence posts and recorded coordinates using a global positioning system (GPS) to ensure the plots could be relocated.

Vegetation Sampling

We measured plant biomass in 25, 1 m x 0.5 m quadrats in 27 plots (at 9 sites) in autumn 1999 and spring 2000 and in 54 plots (at 18 sites) in autumn 2000-2003 and spring 2001-2004. We clipped vegetation 2.5 cm above the ground and separated into species. Samples were oven-dried to constant weight at 65 °C. We summarized the data for species richness (average number of species per plot) and Simpson's index of diversity (average number of species and their relative abundance). Plant species diversity was consistently lower in areas dominated by *E. lehmanniana*.

Richness was not altered dramatically by fire treatment over time ($P = 0.071$ in 2001, $P = 0.248$ in 2002). Although there was considerable temporal variation, plant species richness was consistently highest in plots without nonnative grasses, intermediate in those with moderate levels of nonnative grasses, and lowest in those dominated by nonnative grasses in most seasons. Species richness peaked in spring 2001 likely due to a response by annual forbs to an abundance of winter rainfall. Interestingly, species richness fell sharply in fall 2001 perhaps in response to lower-than-normal rainfall during the summer monsoon of 2001.

Biomass of *E. lehmanniana* on burned plots treated in 2001 was lower than unburned plots and the trend persisted for 1.5-2 years; plots treated in spring averaged 40 g less and plots in summer averaged 75 g less than unburned plots. *Eragrostis lehmanniana* biomass declined after 2002 fires ($P = 0.0137$, Wilks lambda) with average biomass on burn plots 60-80 g less than on unburned plots following the growing season. Regrowth of nonnative lovegrass after fire depended on the year of treatment, likely in response to variations in annual rainfall. Unlike *E. lehmanniana*, the native lovegrass, *E. intermedia*, did not respond to 2001 fires ($P = 0.1268$, Wilks lambda) or 2002 fires ($P = 0.8260$, Wilks lambda).

The relative proportion of Lehmann lovegrass was not influenced by fire regime (Manova, $P = 0.14$). There was a significant interaction between change in biomass over time and vegetation type (i.e., degree of dominance by nonnative grass) (Manova, $P = 0.0009$). On “nonnative” plots dominated by Lehmann lovegrass that were treated in summer 2001, the proportion of Lehmann lovegrass declined during the first two growing seasons but by the third growing season no differences persisted (Fig. 1a). There was an apparent overall increase in the proportion of Lehmann lovegrass over time, particularly in 2003 on “nonnative” plots (Fig. 1). There was no change in proportion over time on “mixed” plots (an equal mix of Lehmann lovegrass and native grasses) treated in 2001; however, the variability in proportion across replicates increased in 2003 (Fig. 2a). Likewise, there was no change in the proportion of Lehmann lovegrass in response to fire on “mixed” plots treated in 2002; there was an apparent increase in the proportion of Lehmann lovegrass in 2003, a particularly dry year (Fig. 2b).

Small Mammal Sampling

We trapped small mammals in 27 plots (9 sites) in spring and summer 2000, as well as all 54 plots (18 sites) in winter, spring, and summer 2001, 2002, 2003, and winter and spring 2004

(see Table 1 for species lists). We sampled small mammals using an 8×8 grid (64/plot) of folding Sherman traps (30 cm, ventilated) for 5 days. We marked captured animals with ear tags and secondary color markings.

Species richness of small mammals was relatively consistent over time, with the exception of slightly higher values in mixed grass communities in 2002 (Fig. 3). Relative abundance of small mammals peaked 2000 in all plant communities, and again in 2002, but only in mixed grass and nonnative grass-dominated communities (Fig. 4). Within most seasons, however, relative abundance was similar across the gradient of nonnative-grass invasion.

Species richness decreased slightly after fires in native and mixed grass communities (Fig. 5), however, patterns differed in nonnative grass-dominated communities. Relative abundance of small mammals decreased during the first year following prescribed fire, especially in mixed grass and nonnative grass-dominated communities, regardless of fire season, compared to unburned control plots (Fig. 6). Two to three years after prescribed fire, both species richness and relative abundance began to approach that observed in unburned plots.

Invertebrate Sampling

We sampled invertebrates using pitfall traps in a 3×3 grid in each plot for 24 hrs concomitant with small mammal trapping periods. We have accumulated a reference collection of over 1000 taxa, which we are in the process of identifying. Approximately three-quarters of all specimens in the collection have been identified to order and family. We will begin data analysis after identification is complete.

Bird Sampling

Between April and September 2000 to 2003 we counted birds seen and heard in 9 ha plots ($n = 45$) 8 times per year ($n = 1440$ surveys). Species richness was relatively consistent both across the gradient of nonnative grass dominance and between burned and unburned areas one to two years post fire (Fig. 7). Similarly, we observed no pattern in relative abundance (number of individuals detected) across the gradient or in areas with varying time since burn (Fig. 8).

We also searched for and monitored the fate of bird nests in both 2000 and 2001. Nests were found by rope dragging and through observations of adult bird behavior. A total of 138 nests were found in 2000, 224 in 2001. Most commonly found nests were those of mourning doves and Botteri's sparrows. Both species richness (Fig. 9) and density (number of nests/9ha; Fig. 10) were positively associated with increasing dominance of nonnative grass. The density association was present not only across the full breeding bird community (all species) but also in subset of the bird community that nested on the ground (Fig. 11). At the scale of an individual species, the same pattern was evident: presence of Botteri's sparrow nests was positively associated with increasing dominance of nonnative grass (Fig. 12).

We used multiple linear regression to assess burn treatment on two bird community characteristics: species richness and nest density. For each model, we used a stepwise selection procedure ($P = 0.25$ to enter, 0.10 to leave) to select from four important covariates in the final analysis: percent cover of nonnative grass, year of observation, and density of trees and shrubs. Between burned and unburned plots we found no difference in species richness ($P = 0.26$) or in density of all birds ($P = 0.78$).

Key Research Accomplishments

Pre-treatment sampling indicated:

- There was a slight negative relationship between biomass of *Eragrostis lehmanniana* and diversity and richness of native species. There was no clear relationship between frequency (number of quadrats containing *E. lehmanniana*) and species richness. Moreover, some plots have relatively low richness despite little or no presence of *E. lehmanniana*.
- Species richness and relative abundance of small mammals were similar across the gradient of nonnative grass invasion. Temporal variability observed may be due in part to variation in rainfall patterns and resulting changes in vegetation.
- Species richness and relative abundance of all breeding bird species were relatively consistent across the gradient of nonnative grass. Nest species richness and density of nests (at three spatial scales) were positively associated with increasing nonnative grass dominance.

Post-treatment sampling indicated:

- Biomass of the nonnative grass *Eragrostis lehmanniana* was related to fire season and to precipitation patterns preceding and following prescribed fires. Richness was influenced largely by seasonal and interannual variation in precipitation than by fire treatments. The relationship between richness and *E. lehmanniana* does not appear to have been affected by fire. There was no positive feedback between the nonnative grass and fire (i.e., increase in the proportion of *E. lehmanniana* to native species after fire). However, on some plots the proportion of *E. lehmanniana* increased regardless of fire treatment.

- Species richness and relative abundance of small mammals decreased during the first year following prescribed fire, compared to unburned areas. The degree of these effects began to decrease during the second year after fire.
- From a community perspective, species richness and density of both individual birds and their nests were relatively constant between burned and unburned areas.

Reportable Outcomes

Manuscripts and presentations

- January 2001 – Three presentations at Malpai Borderlands Group annual science symposium in Douglas, Arizona
 - Fire in southwestern grasslands
 - An experimental approach to assess the effects of fire in southwestern grasslands
 - Future research needs determined by changes in semi-desert grassland plant communities 10 years after cessation of grazing and reintroduction of fire
- April 2001 – Presentation at annual meeting of regional representatives to Department of Defense Partners in Flight at Fort Huachuca Military Reservation, Arizona
- May 2001 – Presentation to Fort Huachuca Conservation Committee
 - Fire effects in southwestern grassland: an experimental approach at Fort Huachuca
- February 2002 – Two presentations at annual meeting of the Arizona/New Mexico Chapters of The Wildlife Society in Safford, Arizona
 - Effects of nonnative grasses on small mammal populations and communities
 - Responses of grassland bird communities to invasion by nonnative grass
- July 2002 – Presentation to Sonoita Valley Planning Partnership in Sonoita, Arizona
 - An experimental approach to assess the effects of fire and nonnative grasses in southwestern grasslands
- August 2002 – Two presentations at Ecological Society of America meetings in Tucson, Arizona
 - Razing Arizona: fire and nonnative grass in semi-desert grasslands
 - Effects of nonnative grasses on small mammal populations and communities
- September 2002 – Presentation at annual meeting of The Wildlife Society in Bismarck, North Dakota
 - Responses of grassland bird communities to invasion by nonnative grass

- August 2003 – Poster presentation at Ecological Society of America meetings in Savannah, Georgia
 - Changes in structure of semi-desert grasslands following restoration of fire
- November 2003 – Poster presentation at Invasive Plant Management meeting in Ft. Lauderdale, Florida
 - The interaction of fire and a nonnative species in semi-desert grassland
- December 2003 – Poster presentation at the 3rd International Wildlife Congress in Christchurch, New Zealand
 - Restoring ecological processes in light of ecological changes
- May 2004 – Presentation at Madrean Archipelago Conference in Tucson, Arizona
 - Response of semi-desert grasslands dominated by nonnative perennial grass to fire season.
- August 2004 – Presentation at the Ecological Society of America meetings in Portland, Oregon
 - Maintaining grasslands: the interaction of fire, climate, and nonnative species.

Employment and Educational Opportunities

This project has supported more than 100 seasonal employees and 3 graduate research assistants. It forms the basis for the research-based education for each of the graduate students, as well as providing educational opportunities and employment for 2 undergraduate researchers. This project also supports training of wildland fire fighting for personnel at Fort Huachuca. Additionally, this research is helping Fort Huachuca comply with Executive Order #13112, the Invasive Species Management Plan.

Conclusions

These preliminary data form the basis for a rigorous, long-term, experimental study of vegetation, small mammals, birds, and invertebrates within the context of invasion by a widespread nonnative plant. This experiment is the first major experimental study of fire and

nonnative plants, and it incorporates responses of all major taxa. Through continued research and future analyses, we will expand our understanding of the impacts of nonnative plants on basic ecological relationships as well as develop management recommendations to minimize the adverse impacts of these species on native biodiversity.

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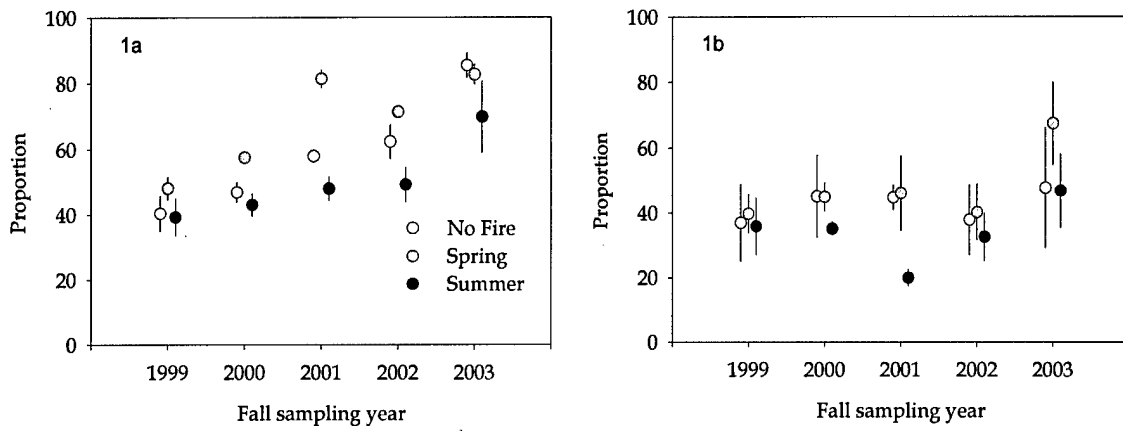


Figure 1. Proportion of Lehmann lovegrass (*Eragrostis lehmanniana*) on plots dominated by Lehmann lovegrass burned in 2001 (Fig. 1a) and on plots burned in 2002 (Fig. 1b).

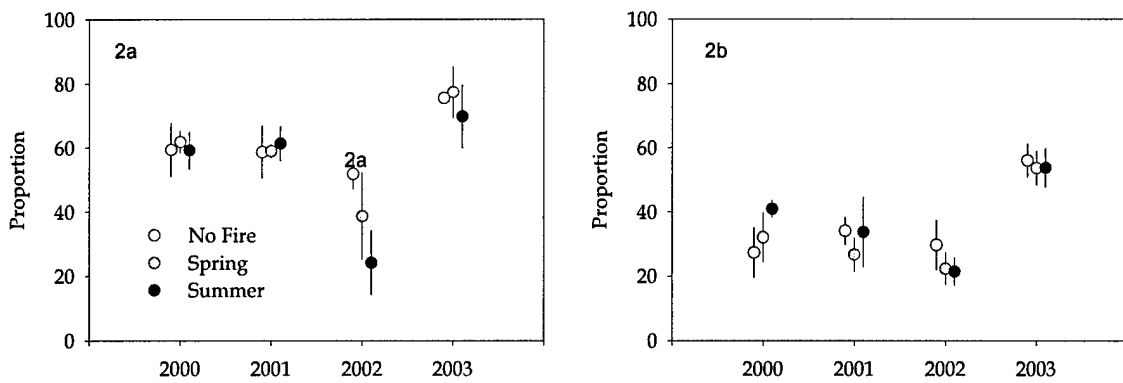


Figure 2. Proportion of Lehmann lovegrass (*Eragrostis lehmanniana*) on plots comprised of approximately equal abundance of Lehmann lovegrass and native grasses burned in 2001 (Fig. 2a) and on plots burned in 2002 (Fig. 2b).

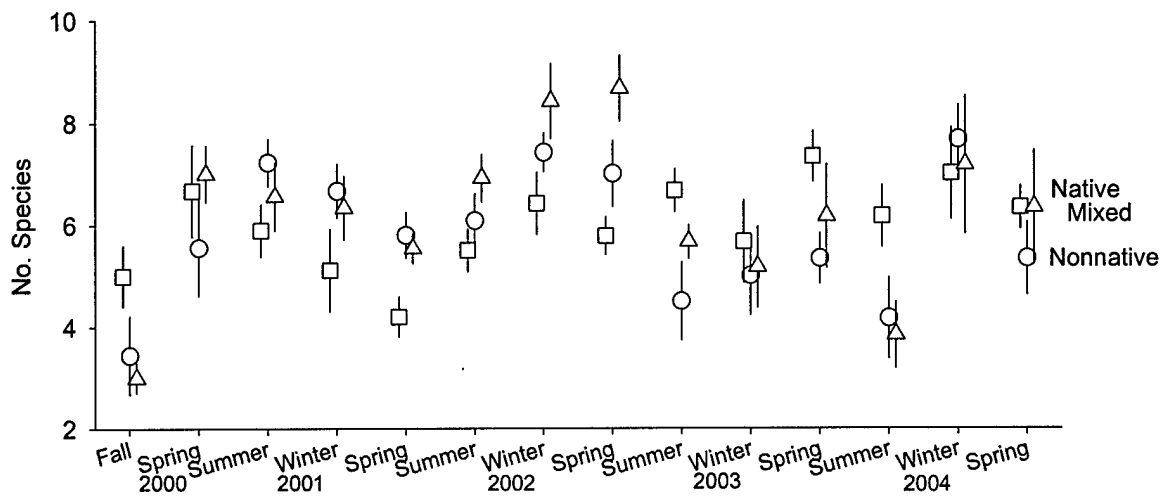


Figure 3. Change in species richness of small mammals over time in unburned plots with no (native), moderate (mixed), and high (nonnative) levels of nonnative grasses. Symbols and error bars represent means and one standard error.

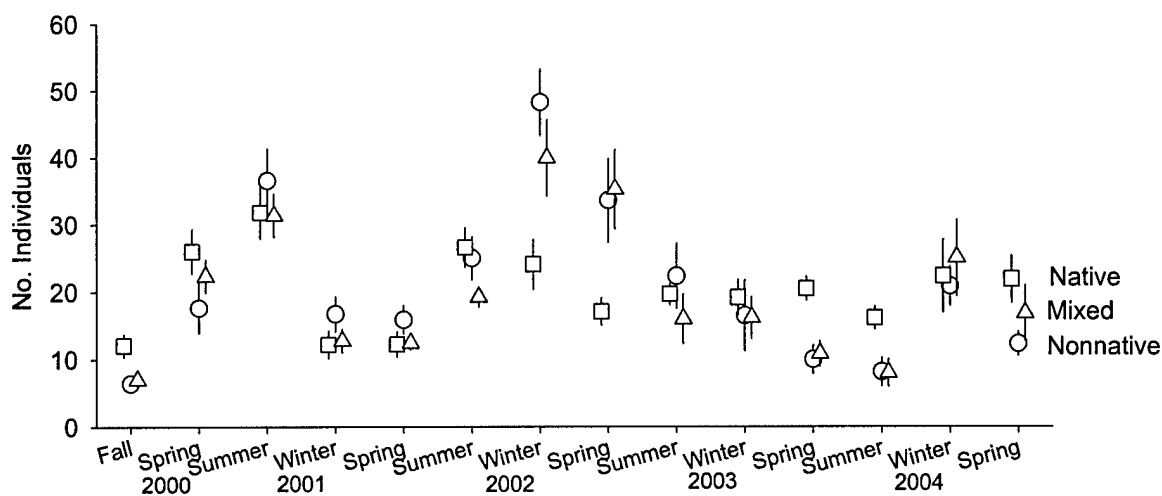


Figure 4. Change in relative abundance of small mammals over time in unburned plots with no (native), moderate (mixed), and high (nonnative) levels of nonnative grasses. Symbols and error bars represent means and one standard error.

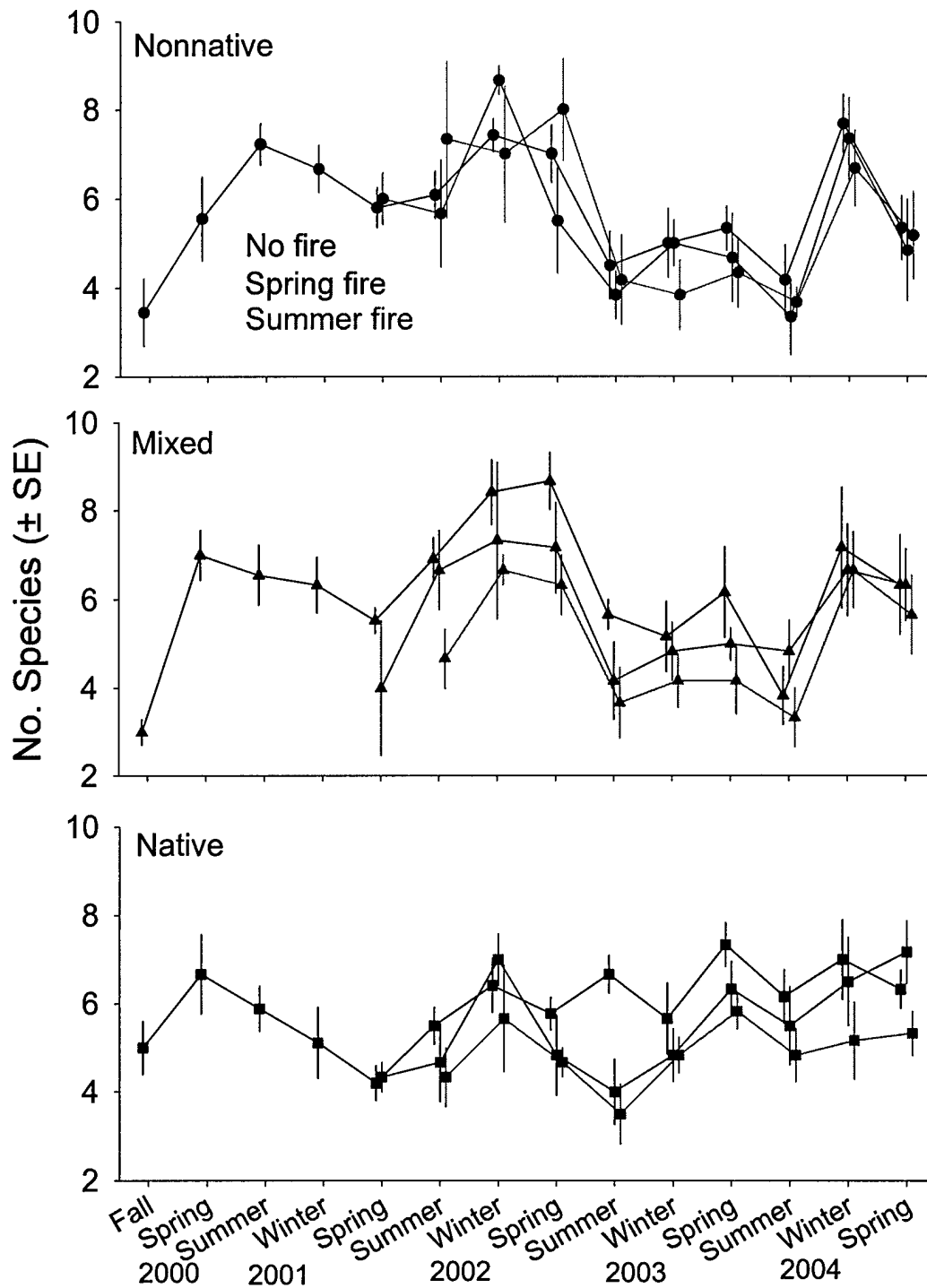


Figure 5. Changes in small mammal species richness over time in plots with no (Native – lower graph), moderate (Mixed), and high (Nonnative – upper graph) levels of nonnative grasses. Black symbols indicate unburned plots, blue symbols indicate plots burned in spring, and red symbols indicate plots burned in summer. Symbols and error bars represent means and one standard error.

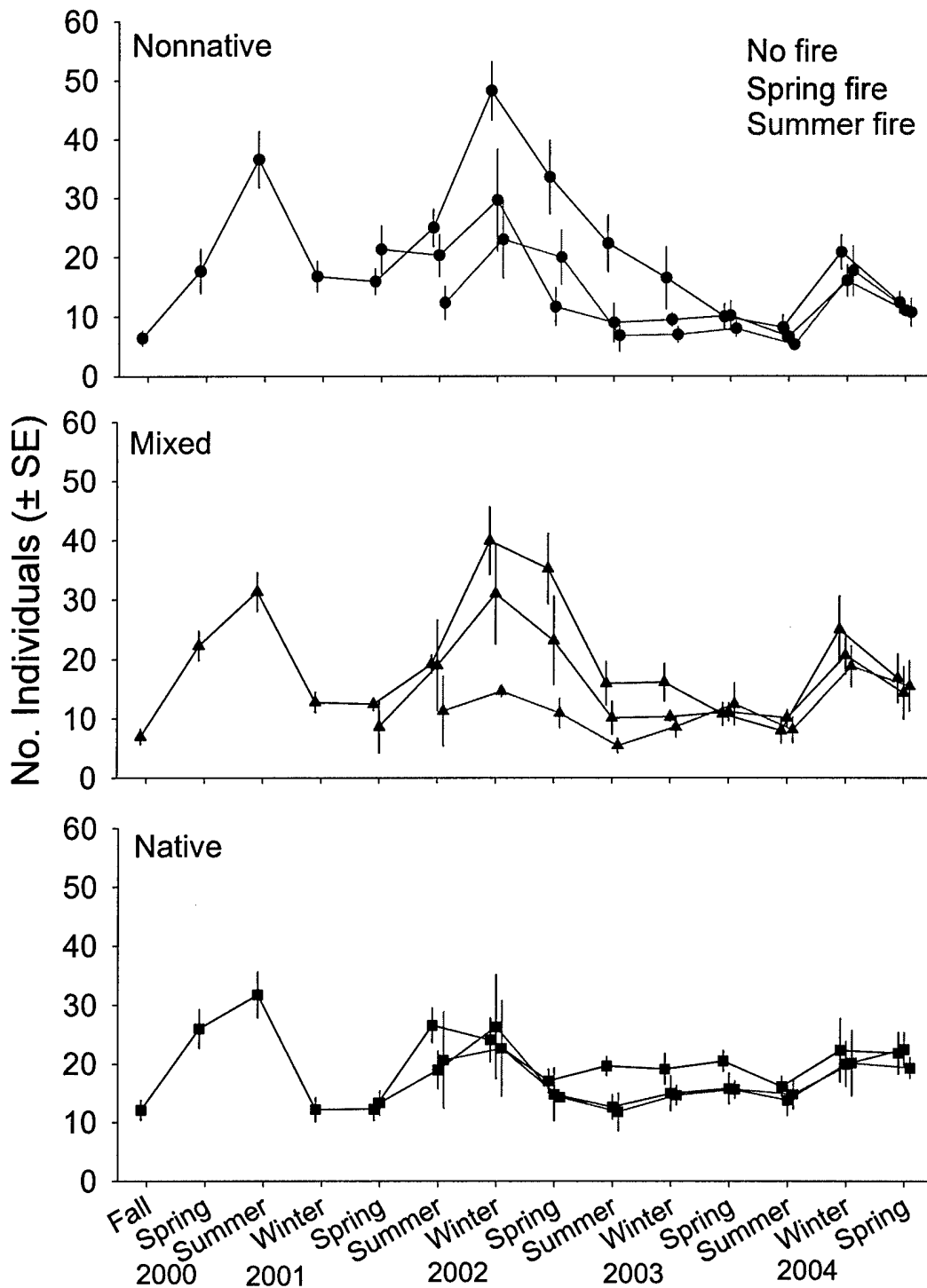


Figure 6. Changes in relative abundance of small mammals over time in plots with no (Native – lower graph), moderate (Mixed), and high (Nonnative – upper graph) levels of nonnative grasses. Black symbols indicate unburned plots, blue symbols indicate plots burned in spring, and red symbols indicate plots burned in summer. Symbols and error bars represent means and one standard error.

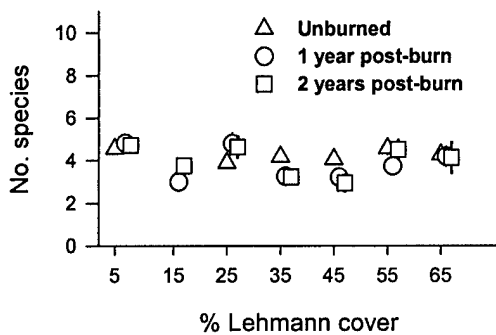


Figure 7. Species richness of birds 1 and 2 years post-burn and in unburned areas across a gradient of nonnative grass dominance.

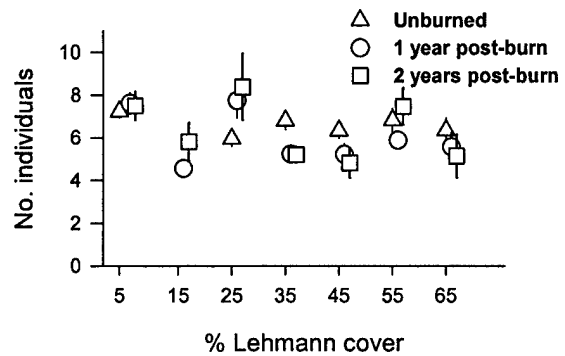


Figure 8. Relative abundance of birds 1 and 2 years post-burn and in unburned areas across a gradient of nonnative grass dominance.

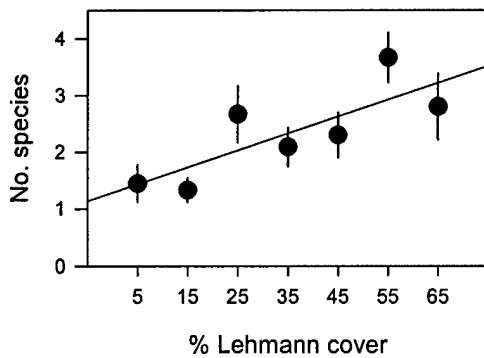


Figure 9. Species richness of birds nesting in areas across a gradient of nonnative grass dominance.

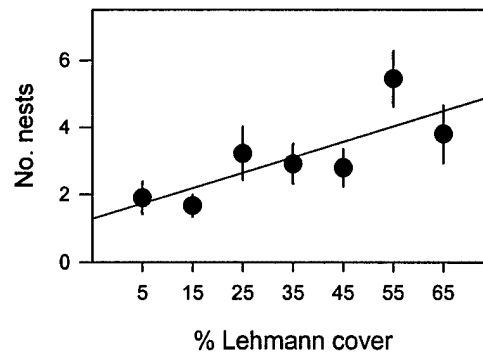


Figure 10. Density (nests/9ha) of nesting birds (all species) across a gradient of nonnative grass dominance.

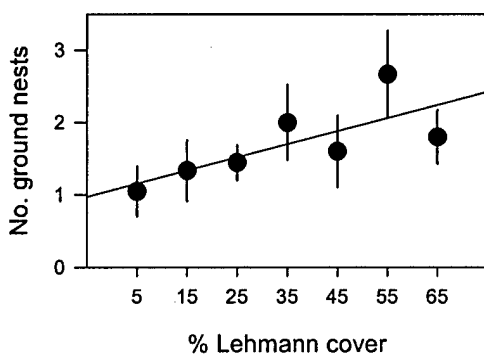


Figure 11. Density (nests/9ha) of ground nesting birds across a gradient of nonnative grass dominance.

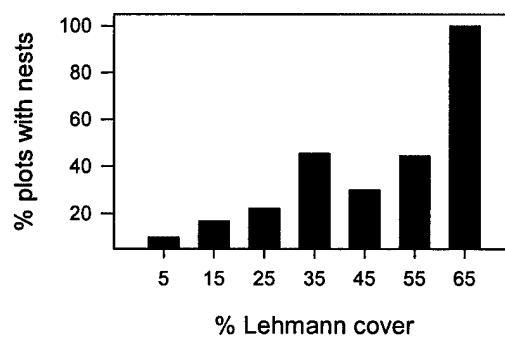


Figure 12. Percentage of plots with Botteri's sparrow nests across a gradient of nonnative grass dominance.

Table 1. Small mammal species captured at Fort Huachuca Military Reservation.

Species name	Common name	Spring 2000	Summer 2000	Winter 2001	Spring 2001	Summer 2001	Winter 2002	Spring 2002	Summer 2002	Winter 2003	Spring 2003	Summer 2003	Winter 2004	Spring 2004
<i>Baiomys taylori</i>	N. pygmy mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Chaetodipus baileyi</i>	Bailey's pocket mouse		X			X	X	X	X	X	X	X	X	X
<i>C. intermedius</i>	Rock pocket mouse	X	X		X	X	X	X	X	X	X	X	X	X
<i>C. penicillatus</i>	Desert pocket mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Dipodomys merriami</i>	Merriam's kangaroo rat	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>D. ordii</i>	Ord's kangaroo rat			X				X	X	X	X	X	X	X
<i>Neotoma albigula</i>	White-throated wood rat	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Notiosorex crawfordi</i>	Desert shrew													
<i>Onychomys leucogaster</i>	N. grasshopper mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>O. torridus</i>	S. grasshopper mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Perognathus flavus</i>	Silky pocket mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>P. hispidus</i>	Hispid pocket mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Peromyscus boylii</i>	Brush mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>P. eremicus</i>	Cactus mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>P. leucopus</i>	White-footed mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>P. maniculatus</i>	Deer mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Reithrodontomys fulvescens</i>	Fulvous harvest mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>R. megalotis</i>	W. harvest mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>R. montanus</i>	Plains harvest mouse	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Sigmodon arizonae</i>	Arizona cotton rat	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>S. fulviventris</i>	Fulvous cotton rat	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>S. ochrognathus</i>	Yellow-nosed cotton rat	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Spermophilus spilosoma</i>	Spotted ground squirrel	X	X		X	X		X	X		X	X		X
<i>Thomomys spp.</i>	Pocket gopher						X			X				
	TOTAL	20	19	19	18	20	18	22	21	22	22	21	21	21